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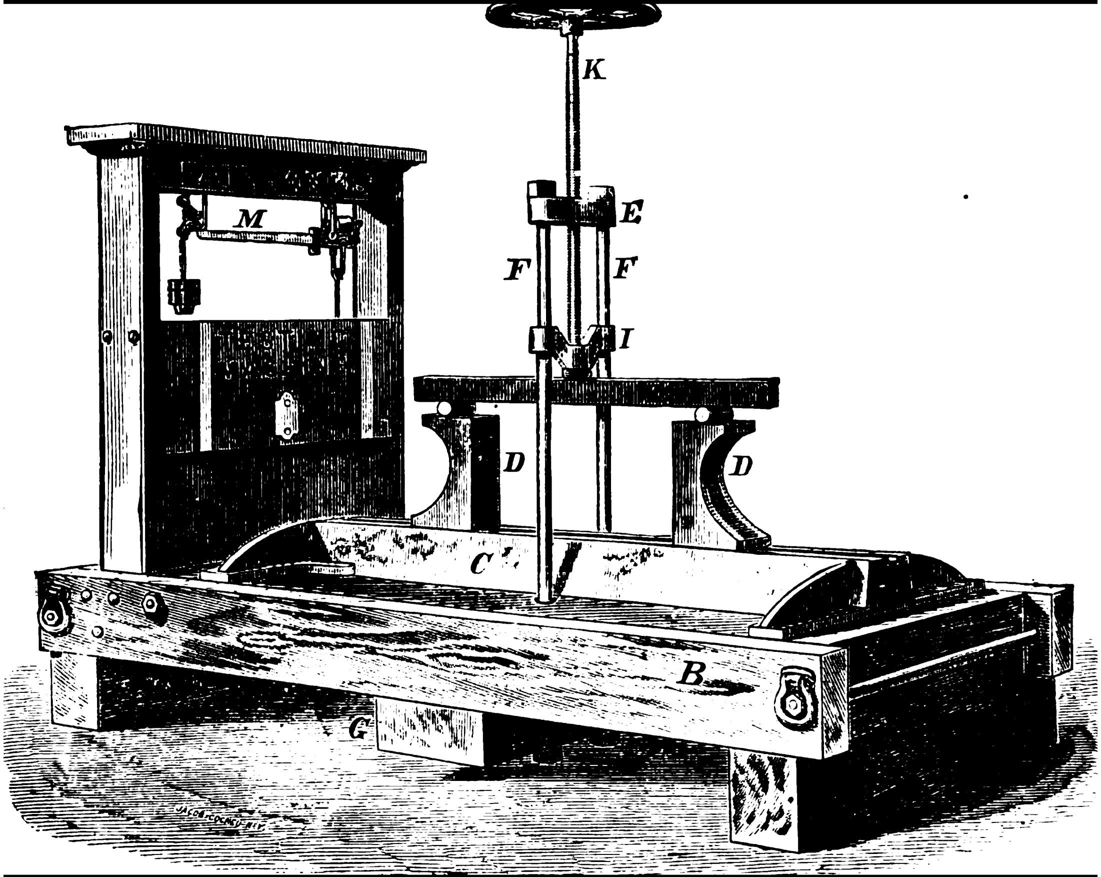

On the strength of American timber

Robert Henry Thurston

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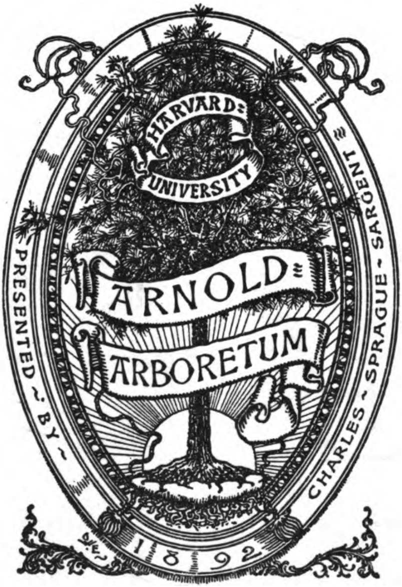

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ON THE STRENGTH

OF

AMERICAN TIMBER.

AN EXPERIMENTAL INVESTIGATION MADE IN THE MECHANICAL LABORATORY OF THE STEVENS INSTITUTE OF TECHNOLOGY.

BY PROF. R. H. THURSTON.

REPRINTED FROM THE
JOURNAL OF THE FRANKLIN INSTITUTE,
For October, 1879.

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ON THE
STRENGTH OF AMERICAN TIMBER.

BY PROF. R. H. THURSTON.

INTRODUCTORY.—One of the earliest investigations planned by the writer when organizing the Mechanical Laboratory of the Stevens Institute of Technology was that here described. Nearly all our knowledge of the strength of timber was derived from foreign sources and was of limited extent, and authorities were somewhat conflicting in statement.[†] It was evident that more work in that department of research was required, and that experiments on the strength of American woods were demanded not only by engineers and architects in the United States, but by members of the profession in Europe, where some American timber—especially our soft pines—is used.

The experiments here described are too few in number, and cover too limited a portion of this field to claim attention as really authori-

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[*] A paper read at the Saratoga meeting of the American Association for Advancement of Science, August, 1879.

[†] Compare Barlow and Tredgold with Laslett. Barlow on the Strength and Stress of Timber, London, 1826; Tredgold's Elementary Principles of Carpentry, London, 1870. Laslett on Timber and Timber Trees, London, 1875.

tative and satisfactorily complete; they will, however, have some value, and may be taken as an initial portion of a complete study of American woods which, it is hoped, may hereafter be made.

The writer desires to express his obligations to the Secretary of the Navy, to the Chief of the Naval Bureau of Construction of the Navy Department and to the Naval Constructor of the Brooklyn Navy Yard for a kindly interest taken by them in the work, and particularly for the important assistance rendered by them in carrying it out.

It seemed eminently desirable that the woods examined and experimented upon should be of the kinds used most generally in construction; that the specimens should be of sound, good stock, and that the test-pieces should be carefully and accurately made to standard size and shape. As the best means of securing these desiderata, the Secretary of the Navy and the Chief of Bureau were requested to furnish test-pieces of the form and size standard in the Mechanical Laboratory of the Stevens Institute of Technology. The favor was cheerfully granted, and the Naval Constructor, on receipt of orders from the Navy Department, prepared the required specimens at the Brooklyn Navy Yard, at the earliest practicable date, taking a personal interest in securing the desired quality of material and accuracy of workmanship. The samples thus furnished may be regarded as well representing those American woods which are here treated of.

The samples furnished were of white and yellow (Georgia) pine, locust, black walnut, white ash, white oak and of live oak.

The characteristics of good pine timber are the following:

It has a close grain and its slow growth should be evidenced by the thinness of the annual rings, which should not exceed a tenth of an inch. The trunk, and consequently its rings, should be symmetrical.

The best timber is charged with resin, which preserves it from decay, and gives it strength and elasticity; its presence is indicated by strong odor. The color of the wood should be a clear tint of yellow and red, alternating, and the texture as well as the colors should be very uniform.

The working of the timber gives a reliable indication of its quality. It should offer considerable resistance to splitting along the grain, it should be strong and free from wooliness, and the cut of the saw, and of the plane or chisel, should leave smooth surfaces. The shavings and chips should be strong and elastic, and the former capable of being twisted about the finger without breaking.

White pine (*Pinus strobus*) is a native of North America, and takes its name from the color of its wood. It grows in all kinds of soil. The best timber is found in cool, damp situations, in the forests of the Northern United States and Canada, between the forty-third and forty-seventh parallels of north latitude. It really flourishes well as far south as Virginia. It grows to great size, reaching a height of upwards of 200 feet, with a diameter of 10 feet at the height of a man's shoulder from the ground. It is the tallest tree in our forests. It sometimes reaches the age of 350 years. Single logs have been cut 36 inches square and 60 feet long.

Its wood is yellowish-white in color, light in weight, rather soft, free from knots, straight grained, and is very easily cut. It is durable only in dry air. It contains very little resin; its leaves are very slender; its cones are very nearly cylindrical and 4 or 5 inches long. Its leaves are pale green in color. Its specific gravity is about 0·7 green and 0·5 seasoned. It is used for light carpenters' and joiners' work, and is remarkably well adapted to pattern makers' use. It has been employed to a considerable extent in building wooden bridges. It is not a very strong wood, and swells or shrinks seriously when the hygrometric state of the atmosphere changes considerably. For many purposes its softness is a serious objection.

The American Yellow Pine, "Spruce Pine," or short-leaved Pine (*Pinus mitis, Pinus variabilis*), is found throughout the country, in dry sandy soils, from New England to Georgia. It is much used in carpentry, and for framing and flooring, and in ship building; it is also used for the masts and yards of large vessels. The trunk is straight and slender. The heart wood is fine grained, moderately resinous, strong and durable. The sap wood is poor in quality, and decays rapidly. Its cones are small; its leaves are in groups of threes, and from 3 to 5 inches long. It attains a height of 60 feet and a diameter of 18 inches.

The Southern Pine, "Long-leaved Pine" (*Pinus Australis, Pinus palustris*), is distributed along the Atlantic coast from Maryland southward, on sandy, light soil. It is probably the most generally useful of our woods, and immense quantities are brought into market.

Its name is sometimes confused with that of the *pitch pine*, and both kinds of wood are known in the Eastern States as *hard pine.*

Both kinds are extensively used by Atlantic ship builders for planking, beams, etc., but seldom for any part of the frame.

The yellow pine sometimes attains a height of 150 feet and a diameter of 4 feet; but the pitch pine seldom exceeds two-thirds this size. The former is principally obtained from the States of Virginia, North Carolina and Georgia, while the latter is abundant in all the Atlantic States south of Chesapeake Bay. The yellow pine required for navy yard use is described as long-leaved, fine-grained Southern yellow pine. Its leaves are light green, 8 to 11 inches long, and rigid; they are dark green in color. The cones are 6 to 8 inches long.

It has but little sap wood, and the heart wood is of very uniform quality, its resinous matter being very regularly distributed. Its grain is fine and close, and it has greater strength, durability and hardness than any other species of pine.

Though not as tough and elastic as white oak, the yellow pine, especially that from Georgia, successfully rivals it in stiffness. If a beam of each kind of timber, equal in dimensions, be suspended by the ends, the oak beam will depart most from its "mould," but will break under about the same load. In dry situations the pine is extremely durable, and where the properties of lightness and solidity are required in combination it is to be preferred to oak. Experiments upon the shrinkage of various woods by Mr. James Jarvis, at the U. S. Navy Yard, Norfolk, Va., indicate that yellow pine should be cut in summer.

The Locust or common Acacia (*Robinia pseudo-acacia*) is a flowering tree, found in the mountainous and hilly portions of the country from Canada to the Southern States.

It grows rapidly and reaches a height of 70 feet with a diameter of 4 feet, but is usually considered full grown if 40 feet high and a foot in diameter. It is a fine ornamental tree.

The wood has a peculiar greenish-yellow color, resembling boxwood slightly. The structure is alternately very compact and quite porous. Its annual rings are thus very distinctly marked.

It exhibits no medullary rays, and the wood has neither taste nor odor. When of good quality it is difficult to cut and work. It is a very valuable timber.

It is especially valued for fence posts and rails, or boarding, but is seldom found of sufficient size and in quantity sufficient to be used in the latter form. It turns well in the lathe and has great torsional strength and resilience, excelling all other common woods in this quality.

The Ash (*Fraxinus excelsior*) *of Europe and the White Ash* (*Frax-*

inus Americana) of America are also valuable timber trees. Their woods have many useful applications. Ash is quite similar in color to oak and in texture to chestnut. It is straight-grained, remarkably tough and elastic, excelling all other common woods, and answers admirably for handspikes, heavy oars, ship blocks, tool handles, the wooden portions and framing of machinery, and for wheel carriages and agricultural implements. It is durable under cover, but decays rapidly if exposed to the weather. The tree grows to a height of 60 feet, and acquires a diameter of 20 inches in rich, moist, loamy soil. It has no observable sap wood.

The Black Walnut (*Juglans nigra*) is found throughout our Middle and Western States, and as far south as the Gulf of Mexico. The tree presents a fine appearance, attains considerable size, and yields a much-prized timber.

The wood varies considerably in quality. It is of a brown color, approaching red in some specimens, and of a dark chocolate color in others. The sap wood is frequently quite light in color. The best wood has a fine grain and a dense structure, although usually excelled in both particulars by good mahogany.

It is strong, durable and easily worked. It is more generally used in the United States for furniture and for ornamental purposes than any other wood, and immense quantities of it are annually worked up. It is nearly as strong as mahogany and is tougher.

The Live Oak (*Quercus virens*) is one of the best known ship-timber trees. It is evergreen and grows on the sea coast from Maryland to the Gulf of Mexico and the Mississippi, and is now so scarce and so valuable that the government has reserved all of the Florida live oak forests for naval purposes.

This timber is used almost exclusively for the purposes of ship building. It is heavy, compact, fine-grained, yellowish in color, and is the strongest and most durable of all American woods.*

The tree grows to a height of 60 feet, and to a diameter of 4 feet, but is usually 40 or 45 feet high and 12 to 18 inches in diameter. The capillary vessels of the heart wood are filled with a gummy substance; unlike other varieties of oak in our country, it is free from acid.

Live oak is not well adapted to the reception of spike fastenings, as the grain refuses to receive the point in the cutting direction, and permits splitting of the wood. There is no difficulty, however, in fastening with bolts and tree-nails. The sap wood is whitish in color, and is free from the glutinous matter found in the dense heart wood. Live oak, if exposed long in the open air, in the rays of the sun, or to winter winds, will check badly. It does not require many months of air-seasoning, however, to fit it for its ordinary uses. It is the most costly ship timber in the market.

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* The writer possesses a live oak cane taken in 1865 from the keel of the frigate *United States*, a naval vessel built very early in the present century. It is as perfectly sound, apparently, as when first cut.

The White Oak (*Quercus alba*) is a more common and a very valuable variety, and is in extensive use, especially for ship building, for which its trunk furnishes the heavier timber, and its large roots and branches yield the "compass timber." It is used for water-wheel shafts and other millwrights' work. The bark is of great value for tanning.

This tree is found from Canada to the Carolinas, and is most abundant in the Middle States, forming large forests west of the Alleghany range of mountains. It reaches a height of 80 feet and more, and its trunk is sometimes 6 or 7 feet in diameter. It is one of the few trees which retain any of their leaves throughout the winter. The leaf is deeply indented, long and narrow. Its bark is of a light grayish-white color, giving it its name; its wood is light straw colored, with a tinge of red, and is very tough, strong, durable, elastic and pliable, with strong lateral cohesion. It is very liable to shrink, warp and crack in seasoning, and is therefore of little value for boards. It is used for artillery carriages and makes very good steps for the lower ends of turbine water-wheel shafts. The shrinkage amounts to about $\frac{1}{32}$.

The wood of trees sixty to one hundred years of age is much tougher, particularly on high lands, than that of older trees. The wood from the roots makes beautiful furniture. The cost and the difficulty of working it preclude its extensive use. No certain data exist for comparing the properties of white oak grown in various districts, but it is generally supposed that the best timber for durability is that grown near the Atlantic seaboard or along the borders of the great lakes. Generally the strongest timber is grown on wet lands. The experiments of Jarvis prove, first, that there is ten per cent. in one year and five per cent. in four years more shrinkage in weight of the squared timber which is cut in the warm season than in that cut during the cold season; secondly, that in case of round logs, in bark, there is eight per cent. in one year and seventeen per cent. in four years more loss by evaporation if cut in the summer season. It has a specific gravity of from 0·7 to 1·1, weighing from 44 pounds dry to 70 pounds when green per cubic foot.

THE FORM AND DIMENSIONS OF TEST-PIECES used in these experiments (see Figs. 1 to 4) were, as at first prepared, given in the accompanying figures:

FIG. 1. Tension.

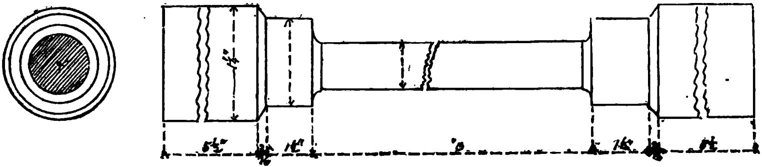


FIG. 2. Compsession.

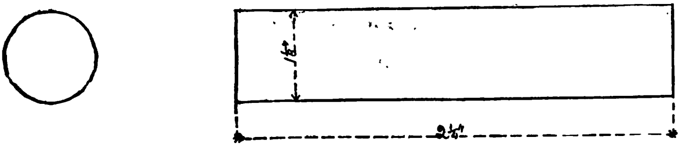


FIG. 3. Transverse.

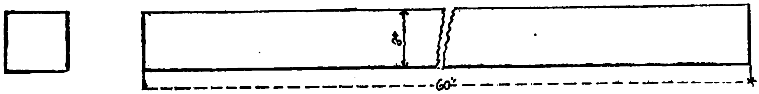
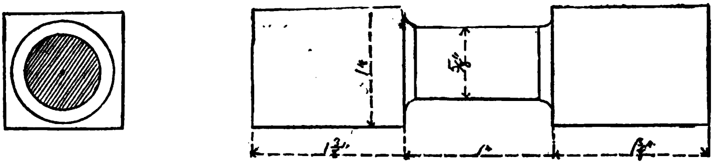


FIG. 4. Torsion.



The white pine here described was of light color and weaker than really good pine should be. Among other samples tested subsequently one bore double the load which broke this. The fact is a good illustration of the great variability observed in the strength of timber. The yellow pine was of fine quality, as were the locust and the oaks. The ash was a little too dry, but otherwise excellent.

The following table exhibits their sizes and densities:

TABLE OF DIMENSIONS AND DENSITIES OF WOODS.

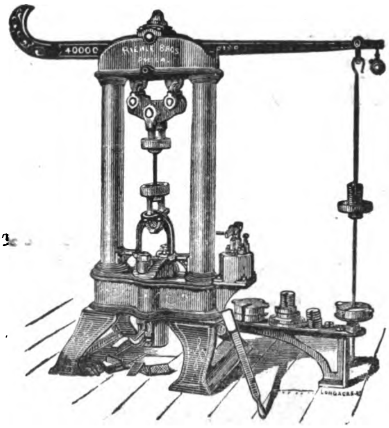
NAME.	No. 1. Tension.		No. 2. Compression.		No. 3. Transverse.				No. 4. Torsion.		Weight per cubic inch in pounds.	Weight per cubic foot in pounds.
	Length.	Diameter.	Length.	Diameter.	Length.	Breadth.	Depth.	Distance between supports.	Length.	Diameter.		
	in.	in.	in.	in.	in.	in.	in.	in.		in.		
White Pine,	4	·537	2·25	1·117	60	3	3	54	1	·780	·0017	29·376
Yellow Pine,	4	·532	2·25	1·102	60	3	3	54	1	·760	·0270	46·656
Locust,	4	·522	2·25	1·078	60	3	3	54	1	·656	·0330	57·024
Black Walnut,	4	·535	2·25	1·112	60	3	3	54	1	·785	·0220	38·016
White Ash,	4	·544	2·25	1·104	60	3	3	54	1	·762	·0200	34·560
White Oak,	4	·481	2·25	1·117	60	3	3	54	1	·780	·0240	41·472
Live Oak,	4	·497	2·25	1·117	60	3	3	54	1	·656	·0390	67·392

THE TESTING MACHINES used in this work were the standard machines of the Mechanical Laboratory of the Stevens Institute of Technology. The tension and compression machine is of a peculiar design, which has never been reproduced, and which was supplied to the writer by Messrs. Riehlé Brothers, of Philadelphia.

It consists of two strong cast iron columns, secured to a massive bed frame of the same material; above these columns is fastened a heavy cross-piece, also of cast iron, containing two sockets, in which rest the knife-edges of a large scale-beam. The upper chuck is suspended by two eye-rods from two knife-edges, ½ inch to one side of centre of a heavy wrought iron block, which is hung by two links from two pairs of knife-edges projecting from the scale beam on opposite sides of the knife-edges of the latter and at equal distances from them, the whole making a very powerful differential beam combination. All the knife-edges are of tempered steel, and the sockets and eyes are lined with the same material, thus reducing friction to a minimum. The load is applied by means of a hydraulic press, with a fixed plunger and movable cylinder; to the latter the lower chuck is fastened by means of an adjustable staple and link. The stress to which the test-piece is subjected is measured by means of suspended weights and a sliding poise. The specimen is secured in the chucks, either by wedge-jaws or cored chucks, according to the specimen to be tested. The capacity of the machine is twenty tons. Fig. 5 exhibits the machine with the sliding poise and adjusting apparatus omitted.

The extensions were measured by means of an instrument in which contact is indicated by an "electric contact apparatus." The instrument consists essentially of two very accurately made micrometer screws, working snugly in nuts secured in a frame which is fastened to the head of the specimen by a screw clamp. It is so shaped that the micrometer screws run parallel to and equidistant from the neck of the specimen on opposite sides. A similar frame is clamped to the lower head of the specimen, and from it project two insulated metallic points, each opposite one of the micrometer screws. Electric connection is made between the two insulated points and one pole of a voltaic cell, and also between the micrometer screws and the other pole. As soon as one of the micrometer screws is brought in contact with the opposite insulated point a current is established, which fact is immediately revealed by the stroke of an electric bell placed in the circuit. The pitch of the screws is 0·02 of an inch, and their heads are divided into 200 equal parts; hence a rotary advance of one division on the screw head produces a linear advance of one ten-thousandth (0·0001) of an inch.

FIG. 5.



A vertical scale, divided into fiftieths of an inch, is fastened to the frame of the instrument and set very close to each screw head and parallel to the axis of the screw; these serve to mark the starting point of the former and also to indicate the number of revolutions made. By means of this double instrument the extensions can be measured with great certainty and precision, and irregularities in the structure of the material, causing one side of the specimen to stretch more rapidly than the other, do not diminish the accuracy of the measurements, since half the sum of the extensions indicated by the two screws is always the true extension caused by the respective loads.*

The machine used for tests of transverse strength was designed by the writer, and built by Messrs. Fairbanks & Co., of St. Johnsbury, Vt. It is shown in Fig. 6.

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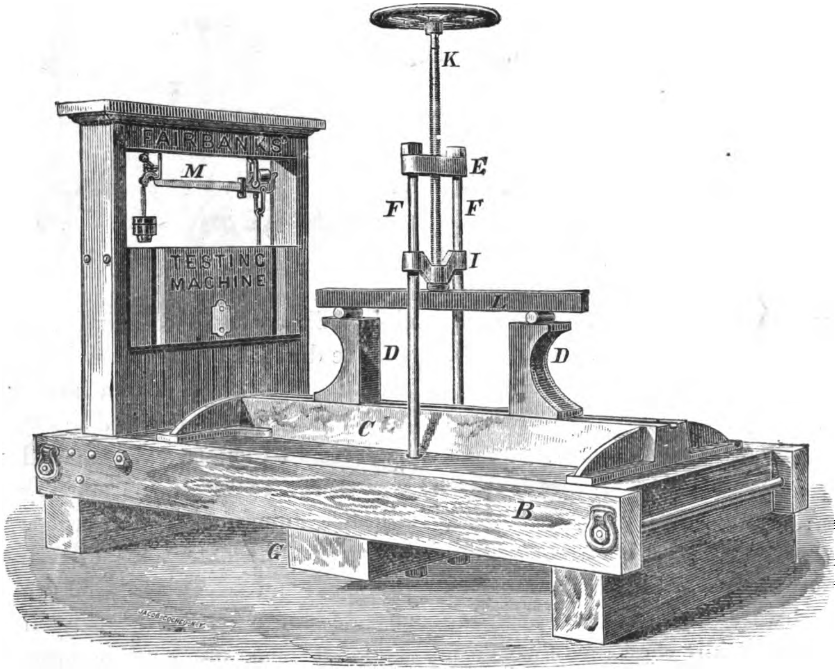
*This instrument is figured and described in a report by the U.S. Board, appointed to test iron, steel and other metals, in an investigation in the Mechanical Laboratory of the Stevens Instituto of Technology: "On the Properties of the Copper-tin Alloys." Washington: Government Printing Office. 1878.

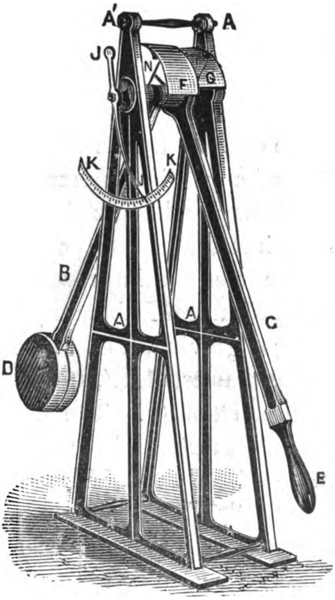
It consists of a Fairbanks scale, on the platform of which rests a heavy cast iron beam, *C*, to which are fastened the supports, *DD*, at the required distances apart. The pressure is applied by means of the hand-wheel on the upper end of the screw, *K*, which screw passes through the nut, *E*, and terminates in the sliding cross-head, *I*. This cross head serves both as a guide and as a pressure-block. The test-piece, *L*, rests upon mandrels mounted upon the supports, *DD*, at the required distance apart. The loads are weighed in the usual manner at *M*.

FIG. 6.



The instrument for measuring deflections is not shown in the cut; it consists of an accurately cut micrometer screw of steel, having a pitch of 0·025 of an inch, working in a nut of the same material mounted in a brass frame. This instrument is supported by a rod of considerable rigidity and of sufficient length, which is secured to the beam, *C*, close to the tension rods, *FF*, in such a manner that the micrometer is directly over the cross-head, in the same vertical plane with the test-piece, and very near and parallel with the axis of the large screw, *K*. The micrometer screw is provided with a head which is divided into 250 equal parts. Thus, a rotary motion of one division produces an advance in the direction of the axis of the micrometer screw of 0·0001 of an inch. A scale divided into fortieths of an inch is fastened to the frame of the instrument, in close proximity to the head and parallel to the axis of the screw; it serves to mark the starting point and indicates the number of revolutions made in taking a measurement with the screw.

Fig. 7.

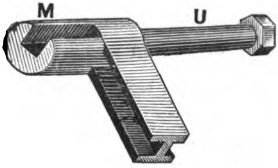


To insure accurate readings of the deflections the principle of electric contact is also employed here.

The capacity of the testing machine is 7000 pounds.

The testing machines used for torsion-tests in the Mechanical Laboratory of the Institute are two styles of "Autographic Recording Testing Machines," devised by the writer. They had previously produced a considerable mass of records which have been, in part, presented by the writer, with interpretations, to the American Society of Civil Engineers.*

Fig. 8.



The machine employed in the earlier tests is shown in Fig. 7. Two strong wrenches, *CE*, *BD*, are carried by the frames *AA*, *A'A'*, and depend from axes which are both in the same line, but are not connected with each other. The arm, *B*, of one of their wrenches carries a weight, *D*, at its lower end. The other arm, *C*, is designed to be moved by hand in the smaller machines, and by a gear and pinion, or a worm gear, in larger forms of the apparatus. The heads of the wrenches are made as shown in Fig. 8, the recess, *M*, being fitted to take the head, on the end of the test pieces, which is usually given the form shown in Fig. 4.

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* See Trans. Amer. Soc. C. E., 1876, *et seq.*

A guide curve, *F*, of such form that its ordinates are precisely proportional to the torsional moments exerted by the weighted arm, *BD*, while moving up an arc, to which the corresponding abscissas of the curve are proportional, is secured to the frame, *AA′*. The pencilholder is carried on this arm, *BD*, and as the latter is forced out of the vertical position, the pencil is pushed forward by the guide curve, its movement being thus made proportionate to the force which, transmitted through the test piece, produces deflection of the weighted arm. This guide-line is a curve of sines. The other arm, *CE*, carries the cylinder, *G*, upon which the paper receiving the record is clamped, and the pencil makes its mark on the table thus provided. This table having a motion, relatively to the pencil, which is precisely the angular relative motion of the two extremities of the tested specimen, the curve described upon the paper is always of such form that the ordinate of any point measures the amount of the distorting force at a certain instant, while its abscissa measures the distortion produced at the same instant.

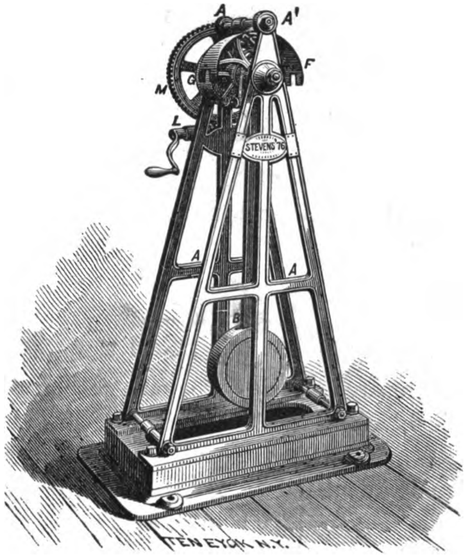
The later and improved form of machine, as now built and used in the Mechanical Laboratory of the Institute, is shown in the accompanying engraving, Fig. 9.

The frames, *A*, *A′*, are bolted to a heavy bed-plate, which secures the required stability. The worm wheel, *M*, engaging with the worm, *L*, has been substituted for the arm, *CE;* the worm is set in motion by means of the crank, *L*, and in this manner a very slow and quite uniform motion can be obtained. Both wrenches are provided with lathe-centres directly opposite each other and in the common axis of rotation. The specimen to be tested is placed upon the lathe centres, which hold it in line while it is being secured in the jaws of the wrenches by means of steel wedges inserted from opposite sides.

Supposing a test-piece to be placed in the machine; the operator turns the crank, *L*, with a uniform velocity which gives a slow and a very steady motion to the wrench connected with the worm wheel, which is transmitted through the test-piece to the wrench carrying the weighted arm. The latter is moved by the force transmitted through the test-piece through an arc, which is a measure of the resistance to torsion offered by the test-piece, and is recorded simultaneously with the angle of torsion by the pencil, as explained above.

The drum carrying the record sheet is of such a diameter that the circumference is 36 inches, which, when divided into tenths, makes 360 divisions, each of which is representative of one degree.

Fig. 9.



In the machines employed in the Mechanical Laboratory of the Stevens Institute of Technology each inch of ordinate denotes 100 foot-pounds of moment to have been transmitted through the test-piece, and each inch of abscissa indicates 10 degrees of torsion. The friction of the machine is not recorded by the machine, but is added in calculating the results.

By means of this machine the metal tested is compelled to tell its own story, and to give a permanent record and graphical representation of its strength, elasticity and every other quality which is brought into play during its test, and to exhibit its characteristic peculiarities.

The machine first described was selected for use in this research and was altered to meet the special requirements of the case. The lever arm, even without the weight, giving too great a moment of resistance for some specimens of wood of the usual diameter, a counterpoise was arranged, consisting of a bar of iron bent to a rectangular shape and clamped to the lever arm below the guide curve, of such a size that, when the lever arm was deflected, it would not interfere with the guide curve. To the top of this rectangle was fastened a vertical iron rod, to which was attached a weight by means of a set screw, so arranged that the continuation of the vertical axis of the lever arm should coincide with the vertical axis of the rod and weight.

In the diagrams produced by the machine thus modified, every inch of ordinate represents 1·058 ft.-lbs. plus the friction of the machine, which in this case is equal to ·52 ft.-lbs.; the horizontal scale is the same as above, *i. e.*, one inch of abscissa equals 10 degrees of twist.

THE EXPERIMENTS were made, as stated, in the Mechanical Laboratory of the Stevens Institute of Technology. The immediate charge of the machines and the observation of results of tests was entrusted to Mr. Frank P. Jones, M. E. (Class of '78), to whose care, skill, industry and persistence we are indebted for a series of very valuable determinations.

The results were tabulated by Mr. Jones, who, under the direction of the writer, also prepared a series of curves graphically representing them. The whole investigation was fully described in a graduating thesis.* The tables here given are usually presented with little or no material alteration as calculated by Mr. Jones in his thesis.

THE TERMS USED may be thus defined:†

The Modulus of Rupture for Tension is the force necessary to pull asunder a bar whose section is one square inch when acting in the direction of the axis of the bar.

The Modulus of Rupture for Compression is the pressure necessary to crush a piece of any material whose section is unity and whose length does not exceed from one to five times its diameter.

The Modulus of Rupture for Transverse Stress is the strain at the instant of rupture upon a unit of the section which is most remote from the neutral axis on the side which first ruptures.

The Modulus of Torsion is the ultimate resistance to torsion of a unit of the transverse section most remote from the axis of torsion.

The Modulus of Elasticity is a value which expresses the relation between the extension, compression or other deformation of a bar and the force which produces the deformation.

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* "Strength of Woods used in Engineering." By Frank P. Jones, M. E, '78. MSS; small 4to; pp. 75; folding plates xvii. Library Stevens Institute of Technology. 1878.

† See Woods' "Resistance of Materials," and "Report," by the writer, "on Cold-rolled Iron and Steel." Pamphlet. Pittsburgh, 1878. And also "Report on the Copper Tin Alloys." Washington: Government Print. 1879.

Resilience is a measure of the capacity of a material to resist shock, and its value is equal to the amount of energy expended, or the "work" performed in producing distortion or rupture.

The tension-tests gave the following results:

RESULTS OF TESTS BY TENSION.

WOOD.	l	d	Modulus of Rupture.	Modulus of Proof Stress	Modulus of Elasticity.	RESILIENCE.		EXTENSIONS. Per ct. of length.	
						Ultimate.	Elastic.	Total.	At elastic limit.
	in.	in.						in.	in.
White Pine,	4	·527	6877·5	3900	183486·2	2467·5	720·0	·725	·400
Yellow Pine,	4	·532	2070·2	13200	240240·2	21457·0	3940·0	1·650	·625
Locust,	4	·522	28925·2	19200	373831·7	31170·0	10792·5	1·850	1·100
Black Walnut	4	·535	9786·4	5700	213523·1	4022·5	1530·0	·850	·525
White Ash,	4	·544	15490·5	97000	206540·4	12695·0	3855·0	1·475	·775
White Oak,	4	·481	13207·8	8100	220130·9	7500·0	3022·5	1·300	.770
Live Oak,	4	·497	10309·2	6300	247505·2	5887·5	2167·5	1·150	·575

In calculating the results of tension-tests, as presented in the table, the *Resilience* was obtained, as in all other cases, by first plotting the results of test and obtaining a curve of which the ordinates measure loads and the abscissas the corresponding stretch or other form of distortion, then measuring the total area of the curve to obtain a measure of total resilience, or shock-resisting power, and by taking the area within the ordinate at the elastic limit as the measure of the elastic resilience.*

The Modulus of Rupture is measured by $R = \frac{P}{K}$; in which P is the load producing rupture, K is πr^2, the sectional area at the point of fracture, and R is the modulus.

The Modulus of Proof Stress is similarly obtained, taking for P the load producing permanent distortion, as measured at the elastic limit.

The Modulus of Elasticity is $E = \frac{Pl}{yK}$; in which its measure, E, is obtained in terms of: P, which is the load at the elastic limit; l is the length of the part stretched, *i. e.*, of the "neck" of the test-piece;

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* The resilience, as usually defined, is *elastic* resilience. It should be carefully distinguished from *total* resilience. The one is proportional to the *work*, or the *vis viva*, required to produce permanent distortions; the other measures that required to produce fracture.

y is the extension at the elastic limit, and K is πr^2, the area of cross-section at the part fractured. The position of the "elastic limit," so called, is necessarily assumed, since, as is seen by examination of the strain-diagrams, which graphically represent the results of these experiments, there is no definite elastic limit, the woods, as was shown by Hodgkinson to be the case with cast iron, having no true elastic limit; but take a set with any load however small. The point assumed is indicated in each case. It may be considered by many that a more strictly accurate measure would be obtained by deducing it from the direction taken by a tangent to the strain-diagram line at its origin. Either method will answer every practical purpose.

The calculations relating to compression were similarly made, assuming that the laws affecting wood under compression are the same as those acting when it is broken by tension—a practically correct assumption where the test pieces, as in this case, are crushed without lateral flexure.

THE RESULTS OF TEST BY COMPRESSION are presented in the following table:

RESULTS OF TESTS BY COMPRESSION.

WOOD.	l	d	Modulus of Rupture.	Modulus of Proof Stress	Modulus of Elasticity.	RESILIENCE.		COMPRESSION. Pr.ct. of length	
						Ultimate.	Elastic.	Total.	At elastic limit
	in.	in.							
White Pine,	2·25	1·117	9592·6	5600	6521·8	19542·6	3534·3	3·498	1·584
Yellow Pine,	2·25	1·102	11952·3	7000	8576·9	16576·56	4107·18	2·906	1·485
Locust,	2·25	1·073	14818·9	9800	8713·8	26551·14	5761·14	3·300	1·617
Black Walnut	2·25	1·112	7001·7	5700	21060·5	5382·6	1561·56	1·254	·528
White Ash,	2·25	1·104	8148·3	5180	17810·0	12788·16	1898·82	2·310	·726
White Oak,	2·25	1·117	7143·5	5600	8029·0	15868·8	3940·86	3·300	1·551
Live Oak,	2·25	1·117	10409·2	6300	14910·5	23150·82	3100·02	3·366	1·056

THE TESTS BY TRANSVERSE STRESS gave results which are exhibited in the succeeding table. Here the modulus of rupture is $R = \sqrt{\frac{3}{2}\frac{Pl}{bd^2}}$; in which expression $P =$ load producing rupture; $l =$ the length of the test-piece between supports; $b =$ its breadth; $d =$ its depth; all measures are in inches, and loads in pounds.

In determining the Modulus of Proof Stress the same expression is used, taking for P, however, the proof load, or the load at the real or assumed elastic limit.

The Elastic and the Ultimate Resiliences here given are the number of foot-pounds of work done in straining the specimens tested to the elastic limit and to the point of rupture respectively, and may be taken as approximate measures of the shock-resisting power of the material.

The Modulus of Elasticity, or the relation of the amount of distortion to the load producing it is determined by the expression: $E = \frac{Pl^3}{48\,\Delta I}$, in which P is the load corresponding to a deflection, Δ, midway between supports; l is the length from support to support; Δ is the amount of deflection, and I the moment of inertia; for these rectangular sections, $I = \frac{bx^3}{12}$.

Results of Tests by Transverse Stress.

Wood.	l	b	d	Modulus of Rupture.	Modulus of Proof Strain.	Modulus of Elasticity.	Resilience.		Deflection.	
							Ultimate.	Elastic.	Ultimate.	At elastic limit
	in.	in.	in.						in.	in.
White Pine,	54	3	3	5280	4320	883636	1364·8	634·8	1·28	·86
Yellow Pine,	54	3	3	16740	12720	3534727	4174·4	2039·6	1·96	·84
Locust,	54	3	3	13680	8400	2046315	4843·2	1259·2	2·70	·82
Black Walnut,	54	3	3	7440	5640	1944000	971·6	433·2	·72	·50
White Ash,	54	3	3	9720	6360	1080000	533·3	1212·6	2·50	1·50
White Oak,	54	3	3	9840	7200	1620000	3660·8	1227·2	1·76	.90
Live Oak,	54	3	3	11280	9040	1851428	4601·6	1462·4	1·38	·94

TESTS BY TORSION were made in the Autographic Machine, modified as already described.

Elasticity is measured by $E = \frac{r}{h}$, in which r is the measure of the recoil on removal of the load, and h the measure of the stress on the diagram taken from base-line.

Stiffness is measured by $S = \frac{m}{o}$, in which o measures the angle of torsion to the point considered (within the elastic limit), and m the value of the corresponding ordinate.

The Modulus is obtained by the expression $E = \frac{ml}{oh^5}$, in which m and o have the values assigned above; l = length of neck of test-piece, and h = its diameter.

The Resiliences, elastic and ultimate, come from the expressions $e = a\frac{m}{R} + F\frac{l}{R}$, and $E = A\frac{m}{R} + E\frac{l}{R}$, in which a is the area of curve to the elastic limit; A is its total area; $l =$ length of abscissa; $R =$ radius of the drum carrying the sheet; $m =$ foot-pounds per square inch of area of curve.

RESULTS OF TESTS BY TORSION.

WOOD.	l	d	RESILIENCE.		Elasticity.	Stiffness.	Elastic Modulus of Resistance to Torsion.
			Ultimate.	Elastic.			
	in.	in.					
White Pine, . .	1	·780	5·10	·235	......	·443	1·534
Yellow Pine, . .	1	·760	12·425	·238	......	1·744	6·878
Locust, . . .	1	·656	14·067	·178	......	1·720	14·159
Black Walnut, .	1	·785	7·396	·238	......	1·088	3·650
White Ash, . .	1	·762	7·381	·560	......	·598	2·328
White Oak, . .	1	·780	12·777	·396	......	·911	3·155
Live Oak, . .	1	.656	14·570	·631	......	·474	3·902

COMPARING AUTHORITIES on the strength of woods, it will be found that the results here recorded usually differ from those obtained by earlier experimenters, and that these figures are almost invariably higher than those of Barlow, Tredgold or Laslett, a fact probably attributable to the very uniform excellence in quality of the specimens tested, although it is possible that they may prove superiority of the American to the European timber.

The American timber, as here tested, gives figures in tension from one-eighth to one-fourth higher than the European woods reported on by Barlow or Tredgold, with the exception of ash. Tredgold's figures for American woods are, however, lower than those here presented, which is evidence of a difference in quality of test-pieces rather than of differences in the varieties of timber. The tables of resistance of timber given in Wood's "Resistance of Materials" accord more closely with those here obtained than do those given frequently elsewhere; they are, however, usually lower than these.

Comparing the results of torsional tests with those previously obtained by the writer,* by a similar method, they were found substantially to agree. The later experiments of Mr. Jones do not exhibit the peculiar phenomenon of a depression and subsequent re-elevation of the curve of the strain diagram which is exhibited in some cases in the earlier records. This may be due to the more complete seasoning of the test pieces last used, or to the action of the modified machine, which was less free from friction, and therefore somewhat less sensitive than was that first used by the writer.

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*"On the Strength, Elasticity, Ductility and Resilience of Materials of Machine Construction, etc." Trans. Amer. Soc. of C. E., JOURNAL OF THE FRANKLIN INSTITUTE, 1874.

In all cases the test-pieces here described were prepared from selected wood, straight-grained, free from knots or other perceivable defect, and may probably be considered as representative of the best quality of American timber, with the exception of the specimen of pine already mentioned. They were measured, when brought to size, by callipers, reading to $\frac{1}{1000}$th inch.

Results were carefully corrected for the local crushing of the wood at points of contact with the machine.

The characteristics of the several woods are best shown by the autographic strain diagrams, of which two sets are given. The one giving the line of recoil when the load was removed at the elastic limit, the other exhibiting the full curve up to the point of final rupture. The areas of these curves were measured very carefully by Mr. Jones, using an excellent planimeter reading to $\frac{1}{100}$th square inch.

The results recorded in this paper are those obtained from the standard set of test-pieces. Repeated experiments on test-pieces from the same timber gave substantially the same results.

American timber has a value, in construction, equal, if not decidedly superior to, European timber.

The strength of American timber, as given by earlier authorities, is probably that of average specimens, and timber may be obtained by careful inspection of very much greater value.

Timber yields, under all forms of stress, to an extent which may be taken, as with cast iron, to be proportional to the load.

From what is above stated, and from a study of the strain diagrams, it may be concluded that the strength of timber is so variable that the only safe course in construction is to assume the highest values, determined by the most uniform series of tests of the material proposed to be used, and then to adopt a high factor of safety.

The tables above given may probably be taken to represent the probable values of resistance of the best selected woods, such as are passed by inspectors for naval purposes.

$$EI\,\frac{d^4y}{dx^4}$$

$E =$ [illegible]

$R =$ [illegible]

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